

A possible long-term activity cycle for ι Horologii: First results from the HK α & SPI-HK α projects

Matías G. Flores^{1,2,5} $\star\dagger$, Andrea P. Buccino^{3,4,5}, Carlos E. Saffe^{1,2,5} and
Pablo J. D. Mauas^{3,4,5}

¹ Instituto de Ciencias Astronómicas, de la Tierra y del Espacio, Casilla de Correo 49, 5400 San Juan, Argentina

² Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de San Juan, San Juan, Argentina.

³ Instituto de Astronomía y Física del Espacio (IAFE, CONICET-UBA), Casilla de Correo 67, 1428, Buenos Aires, Argentina.

⁴ Dpto. de Física, Facultad de Ciencias Exactas y Naturales (FCEN), Universidad de Buenos Aires (UBA), Buenos Aires, Argentina

⁵ Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina.

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ABSTRACT

To detect stellar activity cycles and study the possible star-planet interactions (SPI's), we have developed both HK α and SPI-HK α projects since 1999 and 2012 respectively.

In this work, we present preliminary results of possible SPI's studying the chromospheric activity and look for possible correlations between stellar activity and stellar/planetary parameters. We find that for stars with similar T_{eff} , stellar activity increases with the mass of the planet, similar to previous works. However, stellar ages can also play a role and a larger stellar sample is needed to verify these trends. We also note that some of these stars present a remarkably high level of chromospheric activity, even comparable with RSCvn or BY Dra active stars. In addition, we do not observe any correlation between stellar activity and semi-major axis.

We present the first long-term activity study of the star ι Horologii, a young solar-type star which hosts a non-transiting Jovian planet and presents a high activity level. We analyze our own spectra, obtained between 2002 and 2015, combined with public HARPS observations. We calculate the Ca II indexes derived from the 987 CASLEO and HARPS spectra and convert them to the Mount-Wilson scale. We found a long-term activity cycle of ~ 5 years which fits the *active* sequence of Bohm-Vitense. The amplitude of this longer cycle is irregular, as was also observed for the shorter one. This fact could be attributed to an antisymmetric distribution of active regions on the stellar surface.

Key words: stars: activity – planet-star interactions – stars: ι Horologii.

1 INTRODUCTION

In 1966, Olin Wilson initiated the most-extended program dedicated to the study of the chromospheric activity of several late-F to early-M stars by monitoring the cores of the H and K Ca II lines at 3968 and 3934 Å (see details in Baliunas et al. 1995). This program, performed at Mt. Wilson Observatory between 1966 and 2003, to-

gether with other similar studies, allowed to detect chromospheric activity cycles in several stars of different spectral types, with periods ranging between 2.5 and 25 years (e.g. Wilson 1978; Baliunas et al. 1995; Buccino & Mauas 2008; Flores et al. 2016). The usually accepted model to interpret these stellar cycles is the $\alpha\Omega$ -dynamo, which proposes that the generation and intensification of magnetic fields in these stars is produced by a global-scale dynamo action arising from the coupling of convection and rotation (Parker 1955; Robinson & Durney 1982).

For a sample of stars with well-determined rotation and activity-cycle periods, Saar & Brandenburg (1999) examined the relation between both frequencies and found that most cycles fall into two branches, which they classified as

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 \dagger E-mail: mlflores@icate-conicet.gob.ar

the *active* and *inactive* sequences. In particular, a few stars exhibit cycle periods on both branches simultaneously. For instance, the star HD 190406 (G0V) shows signatures of a short secondary cycle of 2.6 years superimposed on its much longer primary cycle of 16.9 years (Hall et al. 2007). Other stars with multiple activity cycles were reported by Oláh et al. (2009), who studied the time variations of 20 cyclic active stars from decade-long photometric and spectroscopic observations. As a result, they found that 75% of them present multiple cycles with variable cycle lengths. More recently, Metcalfe et al. (2013) detected two simultaneous cycles with periods of 2.95 and 12.7 years in the K2V star ε Eridani (HD 22049). To interpret the $P_{cyc} - P_{rot}$ bimodal distribution, Böhm-Vitense (2007) suggests that probably two different dynamos are operating inside these stars: one driven by rotational shear in the near-surface layers responsible for the longer cycle (active branch), and the other one driven by a so-called tachocline at the base of the outer convection zone (shorter cycle).

ι Horologii (HD17051 = HR 810, $V = 5.4$, $B - V = 0.57$) is a young solar-like F8V star. Kürster et al. (2000) detected a non-transiting Jovian planet ($2.26 M_{Jup}$) at a distance $a = 0.925$ AU orbiting ι Hor with an orbital period of 320.1 days. Although it is a southern star, Vauclair et al. (2008) found evidences in the acoustic oscillation frequencies of the star that ι Hor had evaporated from the primordial Hyades cluster, as Montes et al. (2001) have previously deduced from a kinematic analysis. In particular, Vauclair et al. (2008) estimated the age of ι Hor as 625 Myr. On the other hand, Metcalfe et al. (2010) estimated a rotation period between 7.9 and 8.5 days for ι Hor, consistent with the mean rotation period of solar-type stars in the Hyades cluster (Radick et al. 1995). Due to its short rotation period and young age it is expected that ι Hor presents a higher level of activity than the Sun, in agreement with the widely believed close connection between rotation and activity (Noyes et al. 1984).

From Ca II H and K observations obtained between 2008 and 2010, Metcalfe et al. (2010) reported a 1.6-yr chromospheric cycle for this star, which is one of the shortest chromospheric cycles reported for solar-type stars¹. Following the reasoning of Böhm-Vitense (2007), they associated this short cycle to the *inactive* branch of the $P_{cyc} - P_{rot}$ diagram and suggested that the cycle corresponding to the *active* branch would be close to 6 years. Sanz-Forcada et al. (2013) also detected this 1.6-yr cycle in the X-ray emission, which is the first coronal cycle reported in a solar-like star. They also propose that this short coronal cycle is likely modulated by a longer one. However, this possible longer activity cycle has not been reported in the literature to date.

The discovery of activity cycles in stars with physical characteristics similar to the Sun across a range of age and other parameters is important to understand how typical the Sun is. Also, understanding stellar activity is necessary to discriminate between stellar activity and planetary signals in radial-velocity surveys (e.g. Robertson et al. 2013;

Carolo et al. 2014). For instance, Boisse et al. (2011) separated stellar and planetary signals in radial velocity measurements of ι Hor. To do so, they carried out a simultaneous modeling of stellar activity and planetary parameter for this star. As a result, the authors excluded the presence of a second planet in this system. This study reveals the importance of monitoring the chromospheric stellar activity of stars.

To study the long-term activity in solar-type stars, in 1999 we have developed the HK α project, an observing program at the Argentinian observatory Complejo Astronómico El Leoncito (CASLEO), dedicated to periodically obtain medium resolution echelle spectra of a sample of F to M southern stars (see details in Buccino et al. 2011). Since then, we have systematically observed more than 150 main-sequence stars from F5.5 to M5. To date, we have more than 5500 mid-resolution echelle spectra ($R \sim 13000$) ranging from 3890 to 6690 Å (Vieytes et al. 2005; Díaz et al. 2007; Buccino & Mauas 2008; Vieytes et al. 2009; Metcalfe et al. 2013). Based on our long spectra database, we found the first chromospheric activity cycles in M stars (Cincunegui et al. 2007a; Díaz et al. 2007; Buccino et al. 2011, 2014).

On the other hand, the detection of extrasolar planets around solar-type stars opened a new discussion related to the possible influence of the planet on the level of activity of its host star. On average, 7% of these exoplanets confirmed to date are hot Jupiters (orbital period less than 7 days, a semi-major axis less than 0.1 AU, and a minimum mass greater than 0.2 times the mass of Jupiter) in orbits around F to K solar-type stars². Over this last decade, several works (Shkolnik et al. 2008; Walker et al. 2008; Donati et al. 2008; Krejčová & Budaj 2012; Poppenhaeger & Wolk 2014) showed that the level of activity of the host star can be influenced by its interaction with the exoplanet. In order to explore the star-planet interactions (SPI's) in southern stars, in 2012 we started the SPI-HK α project, a branch of the HK α program, focused specially on stars with hot Jupiters or massive planets in eccentric orbits, which are the best candidates to study SPI's. To compare the level of activity of the exoplanet host stars, we have also taken spectra of stars without planets of similar spectral types.

In particular, we have been monitoring the activity of ι Hor since 2002 and, as a result, we have a long time-series of Mount Wilson indexes obtained between 2002 and 2015, which is an useful tool to search for the possible longer activity cycle suggested by Metcalfe et al. (2010) and Sanz-Forcada et al. (2013). In this work we present a complete analysis of this data, organized as follows. In Section §2 we give an overview of our data, which is complemented by data obtained with HARPS and by the SMARTS survey. In Section §3 we describe our results, and finally we outline our discussion in Section §4.

2 OBSERVATIONS

The observations were obtained at the Argentinean Observatory Complejo Astronómico El Leoncito (CASLEO, San Juan) with the REOSC³ spectrograph located in the 2.15

¹ Recently, using spectropolarimetric observations, Mengel et al. (2016) detected a chromospheric activity cycle (~ 0.32 -yr) in the exoplanet host star τ Boötis (F7V), being the shortest detected cycle up to now.

² <http://exoplanets.eu>

³ <http://www.casleo.gov.ar/instrumental/js-reosc.php>

m telescope. The CASLEO spectra were reduced by using standard IRAF⁴ routines, which carry out the usual reduction process including bias subtraction, spectral order extractions, wavelength calibration and other operations. All the spectra from the HK α and SPI-HK α projects are flux-calibrated. To do so, for each star we also acquired a long-slit spectrum, which was flux-calibrated by using a set of spectrophotometric standards stars. This spectrum was then used to obtain a sensitivity function. As a final step, we combined the flux-calibrated echelle orders to obtain a one-dimensional spectra (see Cincunegui & Mauas 2004, for details).

In Table 1 we show the Mount Wilson S_{MW} index, which essentially is the ratio of the flux in the core of the Ca II H and K lines to the nearby continuum (Vaughan et al. 1978). To compute S_{MW} , for each spectrum we integrated the flux in two windows centered at the cores of the Ca II lines, weighted with triangular profiles of 1.09 Å FWHM, and computed the ratio of these fluxes to the mean continuum flux, integrated in two passbands of 20Å-wide centered at 3891Å and 4001Å. Finally, we used the calibration between Ca II indexes derived from the CASLEO spectra and the Mount Wilson indexes obtained by Cincunegui et al. (2007b).

We complement our analysis with public high-resolution spectra ($R \sim 115,000$) taken between 2003 and 2015 with the HARPS (High Accuracy Radial velocity Planet Searcher) spectrograph, installed at the 3.6 m ESO telescope under the programs listed in Table 2. These spectra cover the spectral range 3781-6912 Å and were automatically processed by the HARPS pipeline⁵. We carefully selected only those spectra with high signal-to-noise ratio to measure precisely the Ca II H and K line-core fluxes. Then, we derived the Mount Wilson S indexes for 957 spectra with a mean S/N ~ 175 at 6490 Å. To do so, we used the calibration procedure explained in Lovis et al. (2011).

In addition, we also included the Mount Wilson indexes obtained between 2008 and 2010 by Metcalfe et al. (2010), and those acquired between 2010 and 2013 presented by Sanz-Forcada et al. (2013). These indexes were derived from spectra taken with RC spectrograph ($R \sim 2500$) on the SMARTS (Small and Moderate Aperture Research Telescope System) 1.5 m telescope at Cerro Tololo Interamerican Observatory (CTIO), and reduced with a standard procedure (see details in Metcalfe et al. 2010).

3 RESULTS

3.1 The first SPI-HK α project results

In Fig. 1 we present the mean Mount Wilson index $\langle S_{MW} \rangle$ distribution of exoplanet host stars under study as a function of the effective temperature. All stellar and planetary parameters (e.g. effective temperature T_{eff} , semi-major axis

Table 1. Observational data and derived Mount Wilson activity indexes for the star ι Hor from the HK α & SPI-HK α projects.

Date*	JD (+2,450,000)	S_{MW}	σ_S
0603	2803	0.213	0.0070
0607	4282	0.232	0.0078
0608	4640	0.243	0.0083
0706	3926	0.231	0.0078
0710	5402	0.237	0.0080
0802	2517	0.201	0.0066
0805	3597	0.250	0.0086
0813	6537	0.255	0.0088
0903	2895	0.222	0.0074
0904	3274	0.247	0.0085
0905	3636	0.246	0.0084
0906	3989	0.224	0.0075
0908	4732	0.222	0.0073
0910	5455	0.246	0.0084
0911	5820	0.240	0.0082
0912	6171	0.228	0.0076
0912	6196	0.224	0.0075
0913	6564	0.257	0.0089
0914	6905	0.276	0.0097
1214	7004	0.265	0.0093
1009	5107	0.242	0.0083
1013	6592	0.253	0.0087
1102	2602	0.195	0.0063
1112	6254	0.244	0.0083
1203	2979	0.225	0.0075
1207	4447	0.230	0.0077
1208	4821	0.234	0.0079
1210	5547	0.248	0.0085
1212	6283	0.225	0.0075
0915	7273	0.223	0.0074

Note: * Month and year of the observation (e.g., 1102 correspond to 2002 November).

Table 2. ID programs of ι Hor observations used in this work.

ESO HARPS programs
078.D-0067(A)
077.C-0530(A)
079.C-0681(A)
078.C-0833(A)
060.A-9036(A)
072.C-0531(B)
072.C-0488(E)
074.C-0012(A)
073.C-0784(B)
076.C-0878(A)
091.C-0853(A)
060.A-9700(G)

a , etc.) were obtained from *The Extrasolar Planets Encyclopaedia*⁶. For comparative purposes, we also include in the figure both the mean Mount Wilson indexes of single stars (without planets) of similar spectral type and those corresponding to very active stars as RSCvn and BY Dra type ones. The index $\langle S_{MW} \rangle$ was calculated from the CASLEO spectra. In Fig. 1, we note that those stars with $T_{eff} \leq$

⁴ IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. under cooperative agreement with the National Science Foundation.
⁵ <http://www.eso.org/sci/facilities/lasilla/instruments/harps/>

⁶ <http://exoplanets.eu>

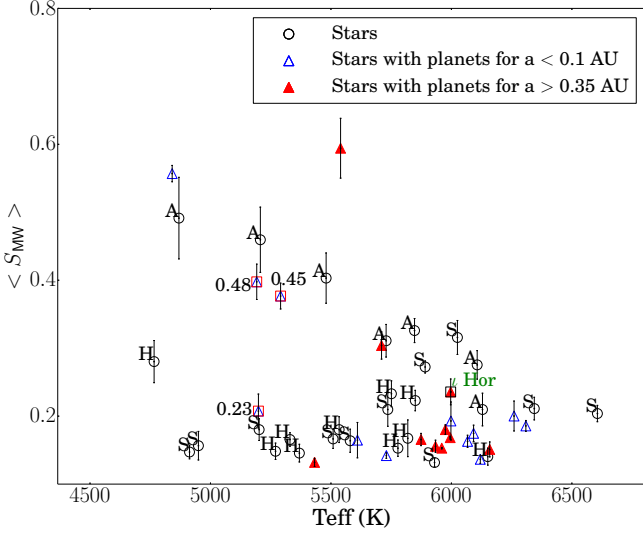


Figure 1. Mean activity level $\langle S_{MW} \rangle$ vs. T_{eff} for stars with and without planets. Empty blue triangles are the stars with hot Jupiters planets ($a \leq 0.1$ AU). Stars with planets located at “larger” orbital separation are indicated with full red triangles ($a > 0.35$ AU). Empty black circles correspond to stars without planets (Single, labeled with S), very active BY Dra and RSCvn stars (labeled with “A”) and high-proper motion stars (labeled with “H”). Empty blue triangles inside red squares indicate those stars of similar T_{eff} ($T_{eff} \leq 5500$ K) with hot Jupiters planets which show high activity levels (labeled with their planets masses). The star ι Hor is indicated with a full red triangle inside a black square.

5500 K which host close-in ($a \leq 0.10$ AU) and more massive exoplanets show elevated activity levels (empty blue triangles inside red squares), similar to that suggested by Krejčová & Budaj (2012). However, this result could be related to the widely believed close connection between rotation (age) and activity. On the other hand, the activity level of hotter stars ($T_{eff} \geq 5500$ K) with planets are in an intermediate activity zone, between very active as RSCvn or BY Dra-type stars and single stars of similar spectral type. In particular, ι Hor (full red triangle inside a black square in Fig.1) is one of the most active exoplanet host star of our sample. In section §3.2 we analyze in detail its long-term activity.

Cuntz et al. (2000) suggested that planets located at distances ≤ 0.1 AU could affect their host stars by magnetic and/or tidal SPI, increasing its chromospheric activity. To search for observational evidences of this increase, in Fig. 2 we plot $\langle S_{MW} \rangle$ vs. semi-major axis a for a set of 12 stars with hot Jupiters observed at CASLEO. It can be seen that there is no significant correlation between stellar activity and semi-major axis. These are, however, preliminary results that should be confirmed with future observations.

3.2 Long-term activity of ι Hor

In Fig. 3 we show the entire data set collected between 2002 and 2015 for ι Hor at CASLEO, combined with the Mount Wilson indexes derived from HARPS spectra obtained between 2003 and 2015. We resampled the HARPS data by using monthly means.

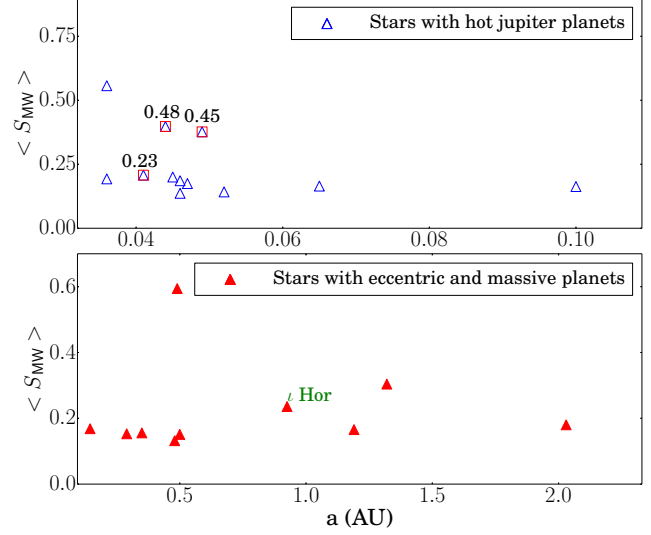


Figure 2. Mean activity level vs. semi-major axis for stars with planets. Top panel: Empty blue triangles correspond to stars with hot Jupiters planets. Empty blue triangles inside red squares and labels indicate the position and the planet masses of the stars with similar T_{eff} plotted in figure 1. Lower panel: Stars which host massive planets in eccentric orbits are shown with full red triangles. We also indicate the position of the star ι Hor.

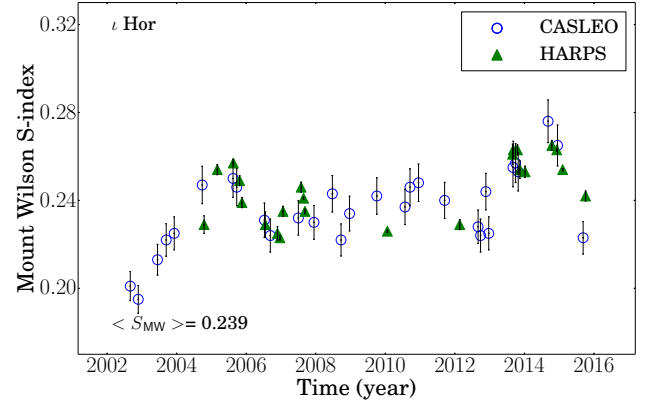


Figure 3. ι Hor. Time series of Mount Wilson index from combined observations. CASLEO data set are shown with empty blue circles and HARPS monthly means with full green triangles.

We estimated the uncertainty of each CASLEO index as the nightly variation during an observing run. To do so, we observed ι Hor during 5 consecutive nights in November and December 2012. We obtained that the Mount Wilson indexes varies between 1% to 3%. Therefore, we considered a conservative uncertainty of 3% for each single observation. On the other hand, we included the average values of HARPS observations associated to the same observing season (HARPS monthly means). Error bars of the average values correspond to the standard deviation of the mean. For those cases with only one observation in a month, we adopted the typical RMS dispersion of other bins. Fig. 3, shows a clear agreement between both time series (CASLEO and HARPS).

To study the long-term chromospheric activity for this combined datasets we computed the Lomb-Scargle peri-

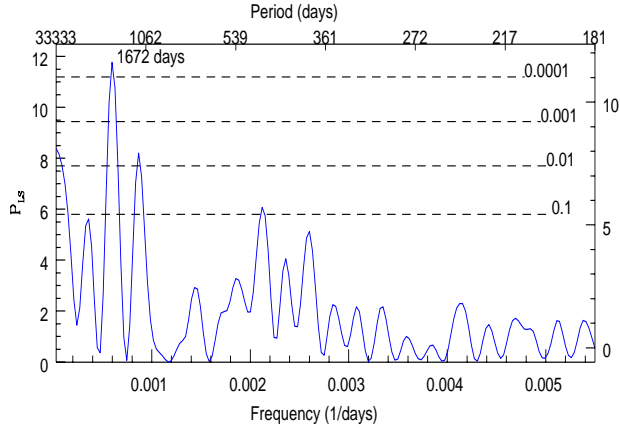


Figure 4. Lomb-Scargle periodogram of the S_{MW} index from the combined data plotted in Fig. 3.

odogram (Horne & Baliunas 1986) as well as the False Alarm Probability (FAP) of the periods, which were obtained by using a Monte Carlo simulation, as described in Buccino & Mauas (2009). We observed a long period modulation of the activity with a cycle of 1672 ± 51 days (~ 4.57 years) with a Monte Carlo $\text{FAP} = 2 \times 10^{-5}$ (Fig. 4). However, we do not detect a significant peak near 1.6 years, which is the one detected by Metcalfe et al. (2010).

According to Böhm-Vitense (2007), in stars with deep convective zones two active dynamos could be operating simultaneously in different regions of the star and, as a consequence, give rise to two different chromospheric activity cycles. Considering the 8.1-day rotation period of ι Hor, if the 1.6-yr cycle detected by Metcalfe et al. (2010) corresponds to the *inactive* branch, the 4.57-yr period detected in this work could correspond to the *active* branch, within the statistical dispersion of the data plotted in Fig. 1 of Böhm-Vitense (2007).

To look for short-term variations, we studied the HARPS and CASLEO indexes after removing the harmonic curve of 1672-day period (see Fig. 5). We obtained a significant period $P = (384 \pm 2)$ days with $\text{FAP} = 0.0007$. However, we suspect that the 384-day period is an artifact. To explore this hypothesis, we used the daily sunspot numbers taken from the National Geophysical Data Center⁷ between 1700 and 2016. We took a sample of the solar data with the same phase intervals that our data, we added Gaussian errors of 10% at each point, and we computed the Lomb-Scargle periodogram. To take different phases of the solar cycle, we repeated this procedure 1000 times with different starting dates. For each periodogram, we considered the period with maximum significance (or minimum FAP) as the detected period. We obtained 72% of the detected period between 9.12 and 13.03 years with $\text{FAP} < 0.001$, which corresponds to the solar-cycle, and in 670 of these 1000 periodograms significant periods with $\text{FAP} < 0.10$ between 326 and 441 days ($384 \text{ day} \pm 15\%$) are also present. This results support the fact that the 384-day peak detected is an artifact.

In Fig. 5, we also detected a less prominent peak

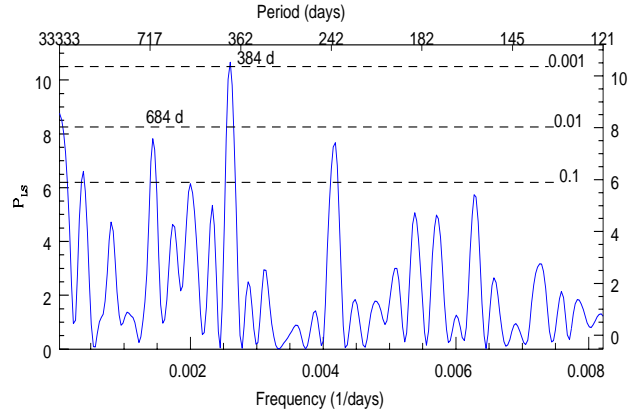


Figure 5. Lomb-Scargle periodogram of the HARPS and CASLEO spectra after removing the harmonic curve of 1672-day period.

at (684 ± 8) days (1.87 years) with $\text{FAP} = 0.016$, which could be associated to the short-term cycle detected by Metcalfe et al. (2010).

On the other hand, in Fig. 3 it can be observed that between 2007 and 2012 the S_{MW} index is rather constant. The Mount Wilson index during this interval varies slightly with an amplitude $\Delta S = 0.013$, from $S_{\text{MW}} = 0.248$ to $S_{\text{MW}} = 0.222$. On the other hand, between 2002 and 2007 the amplitude of the variation is $\Delta S = 0.031$, with a maximum of $S_{\text{MW}} = 0.257$ and a minimum of $S_{\text{MW}} = 0.195$, and between 2012 and 2015 the amplitude is $\Delta S = 0.026$, ranging from $S_{\text{MW}} = 0.224$ to $S_{\text{MW}} = 0.276$.

It is broadly known that from 1645 to 1715 solar activity was flat and the number of sunspots was extremely reduced, although they did not disappear. During this period, called Maunder Minimum, it is estimated that the Ca II K emission was 11% lower than during the current Solar Minimum (White et al. 1992). From the analysis of Mount Wilson indexes registered over 30 years, Baliunas & Soon (1995) reported that 15% of the 111 stars under study are “flat stars”. Some of them are known to be evolved from the main sequence (Wright 2004), while others are dwarf stars that could be in a specially inactive phase like the Maunder Minimum (Judge & Saar 2007). In particular, the active young solar-like star ι Hor could belong to this second group.

Unlike the Solar Maunder Minimum, we observe that the level of activity of ι Hor during the “flat” interval is larger ($\langle S_{\text{MW}} \rangle \sim 0.237$) than the minima of its cyclic phase, reached in 2002 ($S_{\text{MW}} = 0.195$) and in 2015 ($S_{\text{MW}} = 0.224$). Similarly, ψ Ser (HD 140538) also showed a transition from a constant period to a cycling mode, and also in this case the Ca II fluxes in the cycle minima were slightly below that observed during the flat phase (Hall et al. 2007).

On the other hand, between 2008 and 2010 ι Hor was continuously monitored by the SMARTS Southern HK project (Metcalfe et al. 2009), which is a time-domain survey of stellar activity variations. In contrast with our results, Metcalfe et al. (2010) detected the 1.6-year cycle during the “flat” interval observed in our Fig. 3. They continued observing this star until 2013 and confirmed this 1.6-year cycle, which was also observed in X-rays (Sanz-Forcada et al.

⁷ <https://www.ngdc.noaa.gov/>

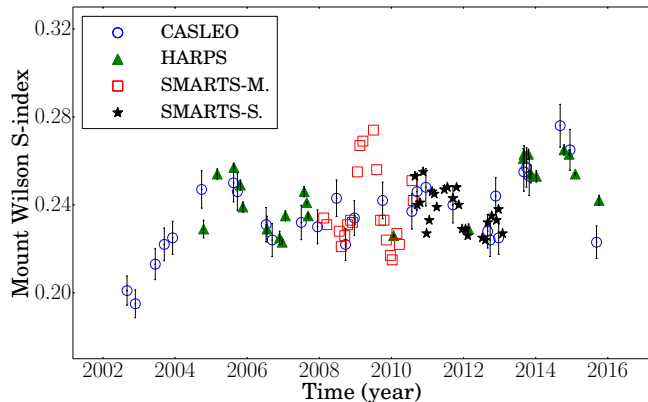


Figure 6. ι Hor. Time series of chromospheric activity indexes from combined observations. CASLEO data are shown with empty blue circles and the HARPS monthly means with full green triangles. SMARTS data from Metcalfe et al. (2010) and from Sanz-Forcada et al. (2013) are shown with empty red squares and black stars, respectively.

2013). However, they found that the amplitude of the three 1.6-year cycles observed between 2008 and 2012 decreased from $A_{cyc} \sim 0.024$ to $A_{cyc} \sim 0.012$ (see Fig. 1 in Sanz-Forcada et al. 2013).

In figure 6 we show our data combined with the average indexes obtained by SMARTS (Metcalfe et al. 2010; Sanz-Forcada et al. 2013). We performed a period analysis for all the combined data set. As a result, we obtained a Monte Carlo FAP of $= 2 \times 10^{-5}$ for our ~ 5 -yr cycle and a FAP of $= 3.61 \times 10^{-4}$ for the shorter one (1.6-yr), much more significant than the one detected in Fig. 5. In addition, it can be observed that between 2007 and 2010 (first 1.6-yr cycle) the SMARTS indexes vary with an amplitude comparable to those observed in CASLEO during the intervals 2002-2007 and 2012-2015 ($A_{cyc} \sim 0.029$ vs. $A_{cyc} \sim 0.031$ and $A_{cyc} \sim 0.026$). On the other hand, the cycle around 2012 has a much smaller amplitude ($A_{cyc} \sim 0.007$). Therefore, the “flat” interval observed in Fig. 3 is not a constant phase, but a short activity cycle with a declining amplitude, as suggested by Sanz-Forcada et al. (2013). In other words, the combined time-series suggest that the flat period seen in the CASLEO data is only caused by sampling.

4 DISCUSSION

Krejčová & Budaj (2012) found evidence that, for stars with $T_{eff} < 5500$ K hosting planets closer than 0.15 AU, their stellar activity is correlated with the mass of the planet. To check this result, we studied 12 stars with hot Jupiters. We observe that for a similar T_{eff} , stellar activity increases with the mass of the planet. Nevertheless, this trend could be related to differences on the stellar age. To explore this possibility, we used the stellar ages computed by Bonfanti et al. (2016), which are 11.9, 5.9 and 5.1 Gyr for less to more active stars, respectively (corresponding to the empty blue triangles inside red squares of figure 1). These data suggest that the observed stellar activity increases are probably the product of differences in stellar ages and are not related to the presence of massive planets. However, recently Pace

(2013) showed that the reduction in the chromospheric activity with age is limited to stars younger than about 2.0 Gyr. On the other hand, we show the distribution of $\langle S_{MW} \rangle$ as a function of semi-major axis. We do not observe any correlation between stellar activity and semi-major axis. A larger sample of stars with and without planets is needed to confirm these preliminary results.

We also studied the long-term activity of the exoplanet host star ι Hor. To do so, we used the Ca II H and K lines as a proxy for stellar activity. We analyzed the line core fluxes of 987 CASLEO and HARPS spectra taken between 2002 and 2015. We detected a long-term activity cycle with a period of 4.57 years with a Monte Carlo FAP of 2×10^{-5} . Metcalfe et al. (2010) reported the presence of a 1.6-yr chromospheric cycle for this star, which was detected by using the Ca II lines from SMART observations. Sanz-Forcada et al. (2013) also found a 1.6-yr cycle in ι Hor in the X-ray emission, which is a direct indicator of the coronal activity of the star.

Considering that some stars show signatures of multiple cycles (e.g. Baliunas et al. 1995; Hall et al. 2007; Oláh et al. 2009; Metcalfe et al. 2013; Rebull et al. 2016) and based in the results of Böhm-Vitense (2007), Metcalfe et al. (2010) and Sanz-Forcada et al. (2013) suggested that ι Hor could belong to this type of stars. They estimated a longer cycle with a period around 6-yr, which is apparently modulating the shorter one. In fact, from Fig. 1 of Böhm-Vitense (2007) it can be estimated a period for the long-term activity cycle (active branch) between 4 and 7-yr. The period we found in the present work fits this active branch within the statistical dispersion of the data in Böhm-Vitense (2007). Furthermore, the stellar activity cycles are not exactly periodic (e.g. Oláh et al. 2009). For instance, the Sun has an average cycle of almost exactly 11 years, however the length of the individual solar cycles fluctuates between 9 and 13 years with a standard deviation of about 1.16 years (see details in Hathaway 2010). In addition, it has a longer cycle with a period of 80~90-year, called the Gleissberg cycle (see e.g., Hathaway 2015) and quasi-biennial variations reported by Fletcher et al. (2010).

An interesting aspect of our time series of Mount Wilson index of ι Hor is the “flat behaviour” observed between 2007 and 2012. In contrast, during that period, Metcalfe et al. (2010) and Sanz-Forcada et al. (2013) found the short cycle for ι Hor. To interpret these differences, we plotted the SMARTS averaged measurements together with CASLEO and HARPS data sets. On one hand, this figure shows in general good agreement between the different data sets. In fact, we can observe that our new measurements follow the expected increase of the new cycle. On the other hand, the analysis of the entire dataset confirm the 1.6-year short activity cycle. These facts suggest that the differences are mainly produced by our sampling, and that frequent observations are necessary to better establish the presence of an inactive phase.

Our results suggest that both the shorter cycle (1.6-yr) and the longer one (4.57-yr) are not regular, which is possibly related with the high inclination of ι Hor ($i \approx 60^\circ$) and the antisymmetric distribution of active regions on the stellar surface, as suggested by Sanz-Forcada et al. (2013).

Kürster et al. (2000) detected a giant planet ($m \sin i = 2.26 M_{Jup}$) orbiting this star, with a period of (320.1 ± 2.1)

days. There are several examples in the literature where a long-period chromospheric signal mimick a planetary signal (e.g. Isaacson & Fischer 2010; Gomes da Silva et al. 2011; Robertson et al. 2013; Carolo et al. 2014). In order to detect a possible second planet in ι Hor, any possible periodic signal should be disentangled to correctly identify its planetary origin. In particular, Boisse et al. (2011) excluded the presence of a second low-mass planets with a period between 0.7 and 2.4 days in ι Hor. In our work we clearly identified a possible ~ 5 -yr long-term cycle related to chromospheric activity, which could point toward the exclusion of a second planet with a similar period.

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